Dispersion uncompensated IM/DD transmissions of 12GHz-wide multi-band OFDM over 100km with a D-EML

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Abstract *Generation of optical SSB signals by a D-EML is extended to its whole bandwidth. In an SSB context, 12GHz multi-band OFDM signal is transmitted through 100km intensity modulation/direct detection dispersive channel without frequency fading.*

Introduction

To reach 40Gb/s in access networks, next generation passive optical networks 2 (NG-PON2)[1] is oriented towards WDM solution consisting in multiplexing 4 channels modulated at 10Gb/s non-return-to-zero (NRZ). Such standardization keeps the intensity modulation/direct detection (IM/DD) architecture mainly for simplicity and low-cost deployment reasons as compared to coherent solutions. Increasing the number of WDM channels to provide higher capacities than what should be provided by NG-PON2 is not attractive in an environment where cost, size and power consumption are crucial and where not much windows are still available in the wavelength spectrum. Increasing the bit-rate per WDM channel seems more interesting. However, the IM/DD channel is frequency selective since the double sideband (DSB) signal resulting from the IM propagates with a frequency-dependent phase velocity through the dispersive fiber and is square-law detected at the receiver side[2]. Moreover, the cost of optical transmitters and receivers is strongly related to their bandwidth. Suppressing one of the two sidebands of the DSB signal, resulting in a single sideband (SSB), allows propagation without frequency fading whereas high spectral efficiency modulation schemes allows achieving higher bit-rate even through bandwidth limited systems. SSB signals are commonly generated with I/Q modulators or optical filters which are both bulky and expensive. In[3,4], we have experimentally demonstrated the generation of SSB signals using a D-EML for 5,3GHz QPSK-OFDM and 4,6GHz 16QAM-CAP signals. Our D-EML[5] is a DFB laser monolithically integrated with an electro-absorption modulator (EAM) with two independent accesses for modulation for both DFB laser and EAM.

In this paper, we combine the high spectral efficiency of OFDM signals with optical SSB signals generated with the small-sized low-cost D-EML to perform transmissions through an IM/DD dispersive channel. The whole bandwidth of the D-EML measured to 12GHz is used for the generation of SSB signals with higher spectral efficiency than conventional NG-PON2 signals thanks to the use of high order constellations.

Operating Principle

Generation of SSB signals by a D-EML relies on the capacity of the DFB laser to act as a frequency modulator (FM) when it is modulated in small-signal regime. The high chirp that a DFB laser may exhibit makes this possible. Meanwhile, the EAM remains a pure intensity modulator. The SSB signal is generated when IM and FM are either 0 or π phase shifted and the ratio between IM and FM indices (m_{IM}/m_{FM}) is equal to 2[3,5]. For wideband modulating signals originating from a common generator, the phase shift occurring between IM and FM varies non-linearly with frequency and depends on several parameters such as the corner frequency[6] of the DFB laser and the difference in electrical length between the two RF access circuits. Moreover, the magnitude of m_{FM} is frequency-dependent contrary to m_{IM} which remains quasi-constant due to the large EAM bandwidth. In order to generate the SSB signal, two digital-to-analog-converters (DACs) are required to modulate separately the DFB laser and the EAM. A pre-emphasis in phase and amplitude on one of the modulating signals is applied to satisfy SSB conditions[3,4].

Experimental setup

The experimental setup used to generate an SSB signal by a D-EML modulated with 12GHz OFDM

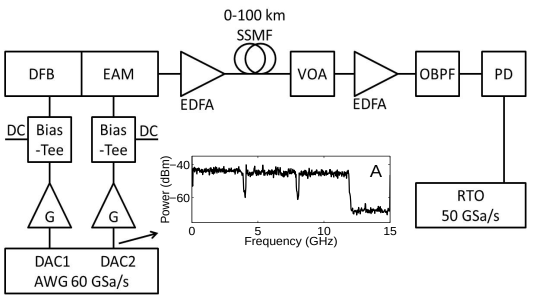

Fig. 1: Experimental setup. AWG: Arbitrary Waveform Generator. EDFA: Erbium Doped Fiber Amplifier. SSMF: Standard Single Mode Fiber. OBPF: Optical BandPass Filter.

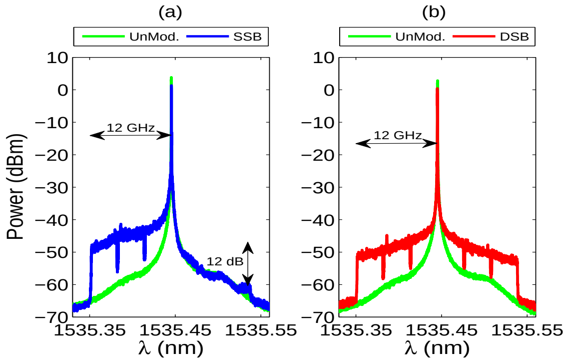

Fig. 2: Experimental optical SSB (a) and DSB (b) spectra superimposed with the DFB laser unmodulated spectrum (Resolution=0,16pm).

signal is shown in Fig. 1. The OFDM modulating signal consists of 3 subbands carried at 2GHz, 6GHz and 10GHz. For each of them, 121 subcarriers out of 128 are modulated by QAM signals (QPSK, circular 8QAM and 16QAM) and 8 samples per symbol are used as cyclic prefix (CP). In order to match the 60GSa/s sampling frequency of the Keysight M8195A AWG, each subband of the signal is oversampled by a factor of 15 before being digitally up-converted to their respective central frequencies. Two copies of the digital signal are used: the first is directly sent to the DAC to modulate the EAM and the second is numerically processed[3] before feeding the DAC and modulating the DFB laser. Analog signals occupy the frequency band [DC; 12GHz] as shown in Inset A of Fig. 1. They are amplified and then superimposed with DC components, i.e. 80mA for the DFB laser and -2,6V for the EAM, before modulating the D-EML. At 80mA, the corner frequency and the linewidth enhancement factor of the DFB laser are respectively measured at 2,2GHz and 2,23. The EAM driver gain is set for the electrical to optical conversion to be performed in the linear region of the EAM transfer function. For the resulting value of m_{IM}, the DFB laser driver gain is adjusted in order to get the required m_{FM}. Optical signals are visualized on a high resolution APEX AP2050A optical spectrum analyzer (OSA). Transmissions are then performed over 25km, 50km and 100km SSMF according to the setup shown in Fig. 1 in both SSB and DSB contexts, for comparison. The latter is obtained by modulating the EAM only. For higher transmission distances, the advantage of a SSB signal over a DSB signal will become clearer. This is because the fading dips of the channel response will move towards the frequency band occupied by the signal [DC; 12GHz] as the fiber length increases. We recall, however, that compared to a directly modulated lasers (DML) IM/DD transmission, we will need higher lengths of fiber to start to see the degrading effects of fiber dispersion and chirp inside our signal bandwidth. This is due to the lower linewidth enhancement factor of our EAM compared to that of a conventional DML. At the receiver side, a variable optical attenuator (VOA) controls the received power. The optical signal is then amplified and filtered to eliminate the amplified spontaneous emission (ASE) noise before being down-converted to the electrical domain with 40GHz photodetector (PD). A real time oscilloscope (RTO) Tektronix DPO72004B operates the analog to digital conversion. OFDM signals are processed offline with Matlab. Transmissions are evaluated in terms of root-mean-squared (RMS) error vector magnitude (EVM) calculated over 300 OFDM symbols.

Results and discussion

The spectrum of the generated SSB signal is shown in Fig. 2-a superimposed with the unmodulated DFB laser spectrum. The sideband power ratio (SBPR) measuring the first order modulation harmonics power ratio exceeds 12dB for all modulating frequencies. The corresponding DSB signal is depicted in Fig. 2-b showing a perfect symmetry between the two sidebands. The advantage of SSB over DSB signals is illustrated in Fig. 3 where the channel response and the EVM per OFDM subcarrier after 25km, 50km and 100km SSMF is plotted for the second OFDM subband. The fading effect on OFDM subcarriers is clear in the DSB context, it moves towards low frequencies when the span is increased[2]. Meanwhile, the SSB context allows propagation without distortion and the EVM remains almost constant.

Performance of OFDM subbands in SSB and DSB configurations with respect to the preamplifier received optical power are shown in Fig. 4, Fig. 5 and Fig. 6 after 25km, 50km and 100km SSMF. Our SSB characteristics and con-

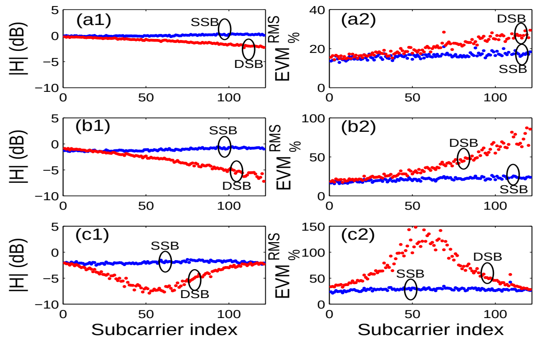

Fig. 3: channel response and EVM per OFDM subcarrier after 25 km (a1-2), 50 km (b1-2) and 100 km (c1-2) SSMF fiber for the second subband (Received power=-17 dBm).

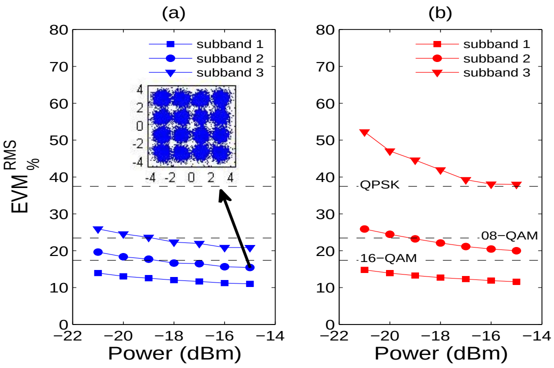

Fig. 4: OFDM subbands performance in terms of EVM in both SSB (a) and DSB (b) contexts after propagation through 25 km SSMF fiber.

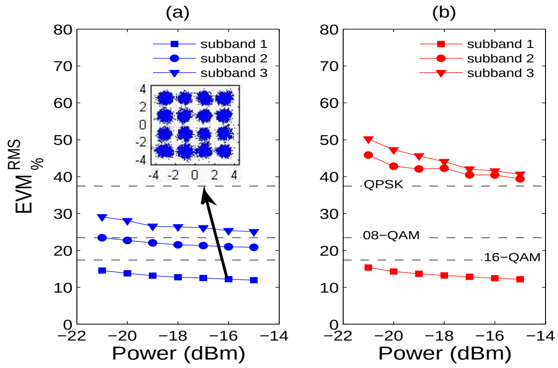

Fig. 5: OFDM subbands performance in terms of EVM in both SSB (a) and DSB (b) contexts after propagation through 50 km SSMF fiber.

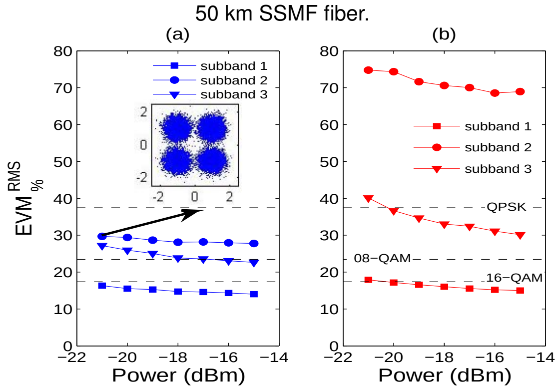

Fig. 6: OFDM subbands performance in terms of EVM in both SSB (a) and DSB (b) contexts after propagation through 100 km SSMF fiber.

stellations on each subband are such that EVM values corresponding to a mean $3,8 \times 10^{-3}$ BER over all subcarriers can be attained. For each of QAM modulations, the EVM corresponding to the BER threshold is specified in dashed lines. After 25km SSMF propagation, the SSB context allows 16-QAM mapping of the first and the second OFDM subbands. The third could be mapped with 8-QAM symbols. Such mapping allows an overall bit-rate of 39,14Gb/s (before the forward error correction (FEC) overhead). Note that we opted for a constant modulation for all subcarriers in one subband. Adaptive modulation could enhance the bit-rate above 40Gb/s. While the first subband exhibits similar performance in both SSB and DSB contexts, the second and mainly the third subbands enlighten clearly the advantage of SSB over DSB signals. SSB signals continue providing interesting performance after 50km and 100km SSMF as the three subbands could be mapped with 16-QAM, 8-QAM and QPSK symbols allowing an overall bit-rate of 32,02Gb/s. On the other hand, performance of OFDM subbands in the DSB context vary considerably as the IM/DD characteristic dips change position when the transmission distance increases[2].

Conclusion

The scalability of the D-EML to generate SSB signals for a modulating signal covering its usable bandwidth is demonstrated. Transmitting high spectrally efficient OFDM signals in SSB optical context allows achieving higher bit-rate through longer distances in access optical networks while avoiding bulky and complex techniques involving optical filtering. When used in 4 channels WDM configuration such as NG-PON2, D-EML could provide 156,56Gb/s over 25km and 128,08Gb/s over 100km IM/DD dispersive channel.

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